Fast Alternative Cryogenic Experiment Testbed (FACET)

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Abstract

The end of regularly scheduled Microgravity Science Payload (MSP) shuttle mission(s), the severely limited ability to accommodate the existing low temperature flight hardware on other carriers, and the anticipated delays in the development schedule for the International Space Station (ISS) in combination have left low temperature microgravity investigations with few (if any) flight opportunities until several years into the next millennium. One of the approaches for improving this situation is the development of a new facility, the Fast Alternative Cryogenic Experiment Testbed (FACET). Although of lesser capability than the planned Low Temperature Microgravity Physics Facility (LTMPF), this simple, low cost, quick response facility would provide frequent flight opportunities before the availability of the Low Temperature Microgravity Physics Facility (LTMPF). After the LTMPF is available, FACET will be available to fly frequently between LTMPF missions, as well as possibly in conjunction with LTMPF. Throughout, FACET will allow the accomplishment of science that does not require the full capabilities of the LTMPF at a reduced cost. We will report on the current design baseline and its envisioned capabilities as well as progress in the construction of a "proof of concept" prototype.

1. Introduction

1.1. Scope

accommodations

This document presents an overview ~~of the Fast~~ Alternative Cryogenic Experiment Testbed (FACET) and the accomodations it is planned that it will provide for low temperature microgravity investigations. ~~Information within~~ this document is subject to change. This document does not contain detailed information regarding the following topics; programmatic selection, interface details, or launch schedules.

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1.2. Applicable Documents

- HHG-730-1503-07, *Hitchhiker Customer Accommodations & Requirements Specifications*, 1994

1.3. Motivation

The end of regularly scheduled Microgravity Science Payload (MSP) shuttle mission(s), the severely limited ability to accommodate the existing low temperature flight hardware on other carriers, and the anticipated delays in the development schedule for the International Space Station (ISS) in combination have left low temperature microgravity investigations with few (if any) flight opportunities until several years into the next millennium. This situation not only delays the completion of existing low temperature microgravity science experiments, but it also compromises the ability to conduct any incremental tests of scientific or technological concepts in microgravity until after the start of the Space Station era. Clearly, flight opportunities within the next few years are necessary to satisfy the science community needs and for timely return of the full benefits of sponsor investment in fundamental physics microgravity science.

Approaches under consideration for improving the current situation include pursuing reflights of the current Low Temperature Platform (LTP) used for the Lambda Point Experiment (LPE) and the Confined Helium Experiment (CHeX) and developing a new facility that maximizes anticipated flight opportunities. The FACET project has as its purpose to pursue the latter approach.

The science objectives to be accomplished within the FACET facility are related to the manipulation and measurement of the thermodynamic variables associated with processes that occur at liquid helium temperatures in a microgravity environment. As envisioned, the FACET facility will complement the LTMPF. At first FACET will serve a "pathfinder" function as LTMPF is developed, as well as serving as a "bridge" facility until LTMPF can be completed. Afterwards, FACET will be available to fly frequently between LTMPF missions, as well as possibly in conjunction with LTMPF. In addition, FACET will allow the accomplishment, at a reduced cost, of science that does not require the full capabilities of the LTMPF.

The ultimate goal of the FACET project is to produce a simple, low cost, quick response facility providing frequent flight opportunities before the availability of the LTMPF. In order to maximize flight opportunities, any facility must minimize the resource impact. Resource impacts include: cost (both development and operation), volume, mass, and telemetry requirements. Flight opportunities between now and the start of the station era can also be maximized by targeting an existing shuttle carrier with the highest probability of manifest opportunities.

2. Mission Design Concept

This section provides a summary overview of the misson and research capabilities it is envisioned that FACET will make available to the researcher.

2.1. System Concept

The FACET facility consists of several different subsystems, that in combination provide both the experimental environment, as well as the instrument control and readout thereof, to conduct low temperature microgravity investigations. The FACET flight configuration is shown in Figure 2.1. The flight configuration uses two umbilically attached adjacent Hitchhiker siderail (HH-S) mounting locations; one for the electronics subsystem, and one for the cryostat subsystem.

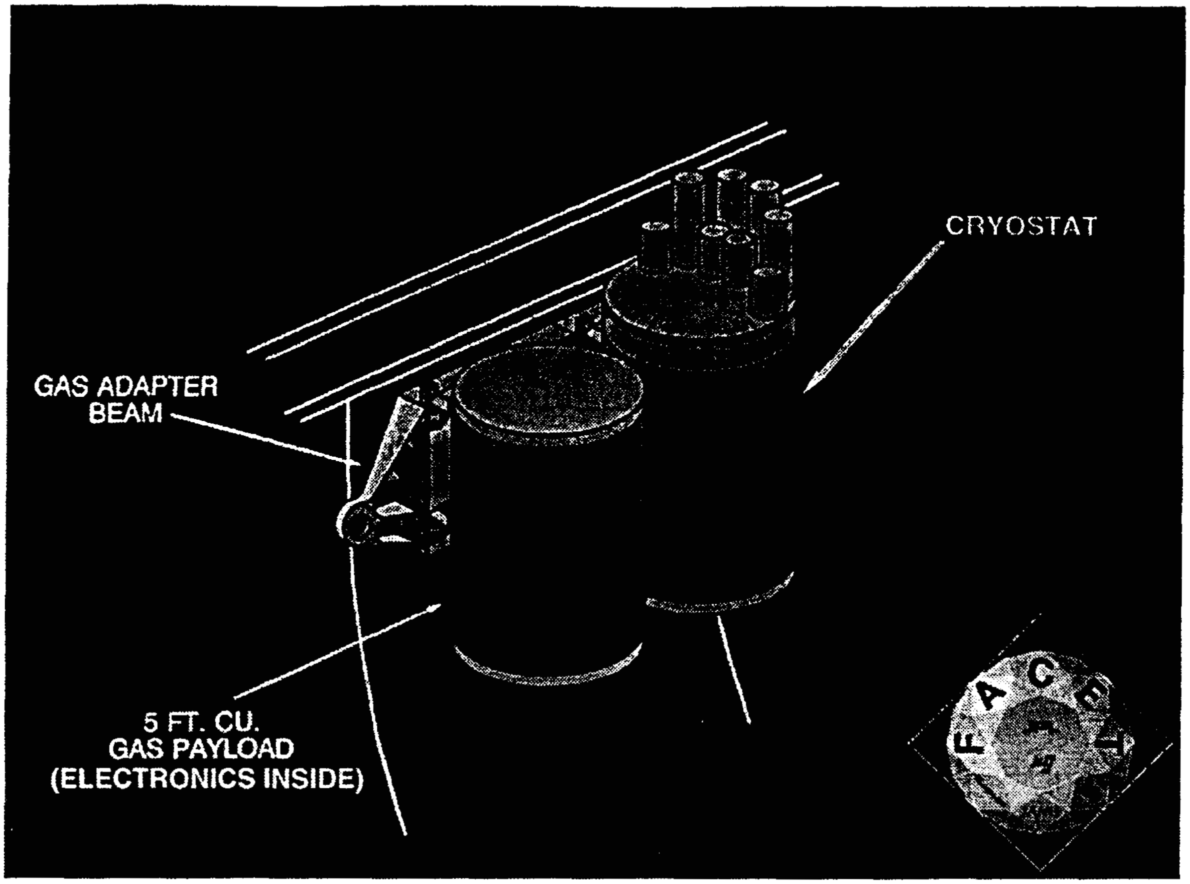

Figure 2.1 FACET facility design concept

The flight system consists of a cryostat subsystem which houses the science instrument subsystem, and mounted next to the cryostat, an electronics subsystem, which provides power handling, instrument and cryostat readout and control, as well as environmental monitoring. A schematic block diagram of the flight system is shown in Figure 2.2.

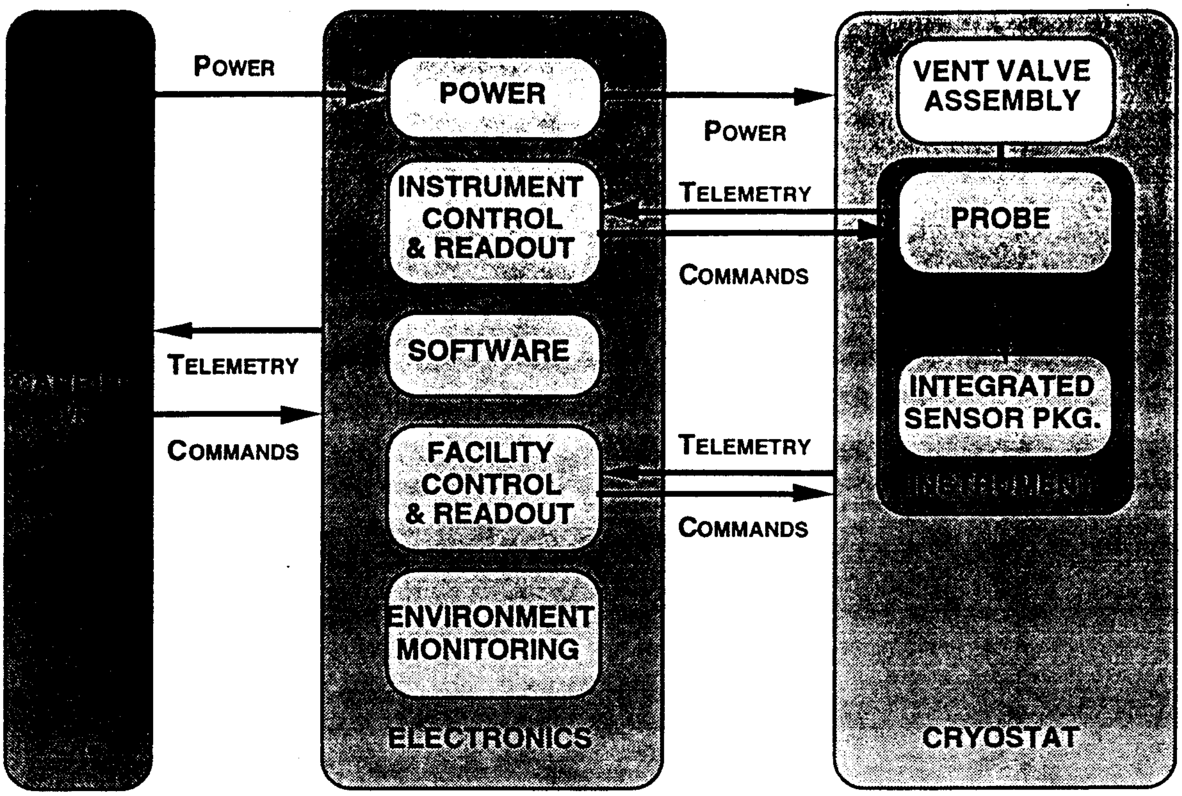

Figure 2.2 FACET system block diagram

2.2. Hitchhiker Siderail Carrier

Payloads are accomodated in the space shuttle by way of carriers. Each of these carriers brings with it a fixed set of capabilities (mass, volume, telemetry, etc.) which in turn affects their manifesting opportunities. A carrier trade study was conducted for the FACET concept, and it was determined that the carrier whose capabilities most closely matched the capabilities of the current Low Temperature Platform, with the highest probability of manifesting opportunities, with the lowest demand on resources, was the Hitchhiker siderail (HH-S) carrier.

Many aspects of the HH-S carrier increase the probability for manifesting opportunities. Hitchhiker has historically been manifested 4 times a year, and has flown along with a wide range of payload masses. Hitchhiker payloads have flown during: a (5,586 lb.) TDRSS satellite deployment mission, MIR servicing missions, SPACELAB pressurized module missions, as well as the United States Microgravity Payload (USMP) series on which LPE and CHeX flew. Moreover, it is expected that Hitchhiker payloads will fly on a "mass available" basis during the building phase of the ISS. The roughly order of magnitude smaller mass of the hitchhiker when compared to other carriers promises more opportunities.

The Hitchhiker project was established by the NASA Headquarters Office of Space Flight (OSF) to develop and operate carrier systems for low-cost and quick-reaction accomodation of secondary payloads on the Space Shuttle. NASA defines payload categories as follows. Primary payloads weigh more than 8,000 pounds each; their requirements may determine Shuttle mission parameters such as orbit altitude and inclination. Secondary payloads are accomodated in space remaining after manifesting primary payloads; weighing less than 8,000 pounds each, their requirements can not determine major mission parameters.

Tertiary payloads are accomodated in space remaining after manifesting primary and secondary payloads; these currently consist of Get Away Special (GAS) payloads already in the GAS queue.

The Hitchhiker carriers can carry payloads side mounted in the Shuttle payload bay (HH-S) or mounted on a (larger) cross bay "bridge" structure (HH-C). Both are depicted in the Hitchhiker project logo shown in Figure 2.3

Figure 2.3 Hitchhiker logo showing payload accomodation locations

2.3. Mission Profile

This section provides a representative schedule of activities for the use of FACET, if developed as a flight facility. The schedule given in Table 2.1 is provided to help familiarize prospective experimenters with the activities and milestones associated with low temperature microgravity flight experiments.

System level activities begin with the delivery of ~~of~~ the PI's flight instrument to JPL and ends after post flight checkout. System integration & test is complete when the PI specific hardware is installed and working within the flight facility. Environmental test verifies the system's compliance with shuttle requirements associated with the launch and/or space environment. Tests may include; random vibration tests, modal tests, thermal/vacuum tests, and electromagnetic interference (EMI) tests as well as electromagnetic compatibility (EMC) tests. Before the system leaves JPL, all shuttle safety verification requirements (analysis, etc.) must also be completed.

The next level of integration and testing occurs at the Goddard Space Flight Center (GSFC) in Maryland where the flight system is combined with the carrier and tested for EMI/EMC compatibility at the payload level.

The hardware is then shipped to Kennedy Space Center (KSC) in Florida. After a post shipment checkout, the hardware is integrated with the shuttle orbiter in the Orbiter Processing Facility (OPF). From here the orbiter proceeds to the Vehicle Assembly Building (VAB), where among other things, the shuttle is integrated with the Solid Rocket Boosters (SRBs). During this approximately week long period there is no payload access. The shuttle then rolls out from the VAB to the launch pad, where the payload is accessible again. Payload access at the pad can take place from the arrival of the shuttle at the launch pad (approximately 1 month before launch) until 65 hours before nominal liftoff (L-65 hours). Launch windows (depending on mission) can last from less than an hour to no more than 96 hours. Following the LPE/CHeX timeline, within 2 days after launch the system is pumped down & calibrated and ready to begin measurements in microgravity. After the shuttle lands, de-integration of the system from the shuttle and the hitchhiker carrier is followed by any post flight testing and calibration that is required by the individual investigator.

Table 2.1 Flight System Timeline

Event	Start	End
System Integration & Test	L - 9 months	L - 7 months
Environmental Test (@ JPL)	L - 7 months	L - 4 months
Payload Integration & Test @ GSFC	L - 4 months	L - 3 months
Checkout & Verification @ KSC	L - 3 months	L - 2 months
Orbiter Integration & Test @ KSC	L - 2 months	L - 1 months
Launch Pad Operations	L - 1 months	L - 65 hours
Nominal Launch	L - 0	
Last Launch Attempt	L + 96 hours	
On Orbit Activation, Equilibration & Calibration[a]	L - 0	L + 2 days
Science Measurements	L + 2 days	L + 7 – 14 days[b]
Post Flight Checkout, De-integration	L + 1 month	L + 3 months

[a] Assumes launch at nominal L - 0

[b] Duration is mission dependant

2.4. Data Acquisition & Analysis

In manner nearly identical to the USMP missions, payload command and telemetry is achieved through Ground Support Equipment (GSE) Workstations at a Payload Operations Control Center (POCC) via the Johnson Space Center (JSC). The Hitchhiker POCC is at GSFC. NASA will provide computer compatible media of the payload data and standard orbit, attitude, and ancillary data for test purposes and for flight acquired data. The flow of payload command and telemetry data is shown in Figure 2.4

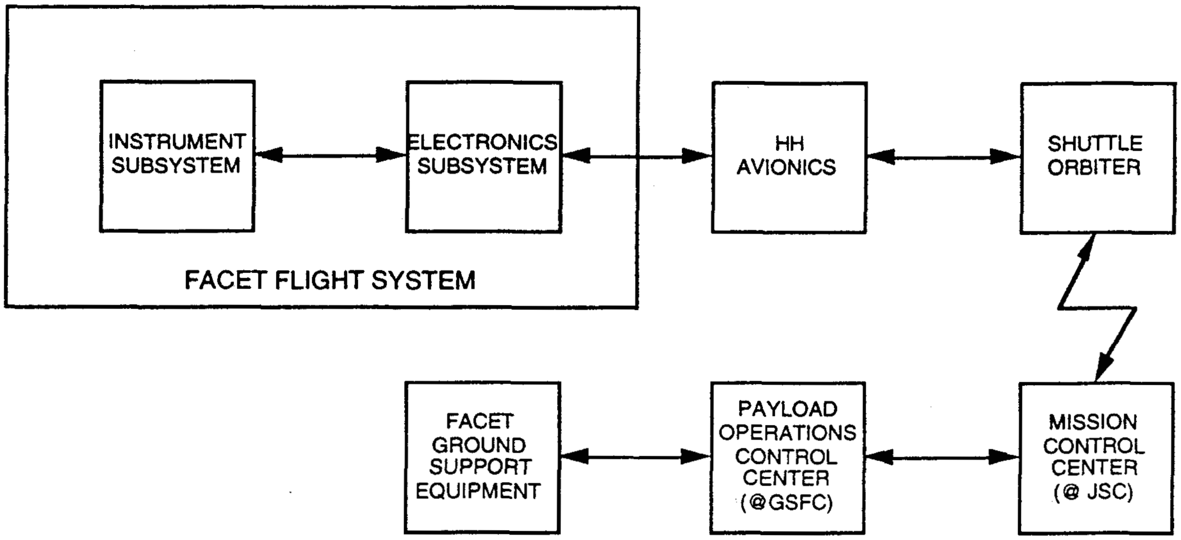

Figure 2.4 FACET end to end information system

3. Cryostat Subsystem

The FACET flight cryostat configuration is shown in Figure 3.1. Unlike the superfluid helium dewar that flew LPE and CHeX, or the planned LTMP Facility, the FACET cryostat is a hybrid Solid Neon - Superfluid Helium dewar. The solid Neon "guard" reservoir around the Helium reservoir minimizes the heat leak into the Helium reservoir in order to meet the functional requirements of operating within the constraints (particularly volume & mass) of the Hitchhiker carrier. The main reasons to choose solid Neon as "guard" cryogen are the following :

- The temperature of solid Neon ($\leq$ 24K) is much lower than that of the more commonly used cryogen Nitrogen (77K). The radiation heat load on the Helium reservoir is thereby reduced by more than 2 orders of magnitude.
- Solid Neon has relatively large heat of sublimation (~ 105 Joule/gm).
- Solid Neon is very dense (1.444gm/cc) and will therefore not occupy too much space.
- Solid Neon is adequate to use because of its mechanical properties. When the liquid Neon solidifies, insufficient stress are generated to deform the metal reservoir.
- Neon is a safe substance to use, in contrast to Hydrogen.

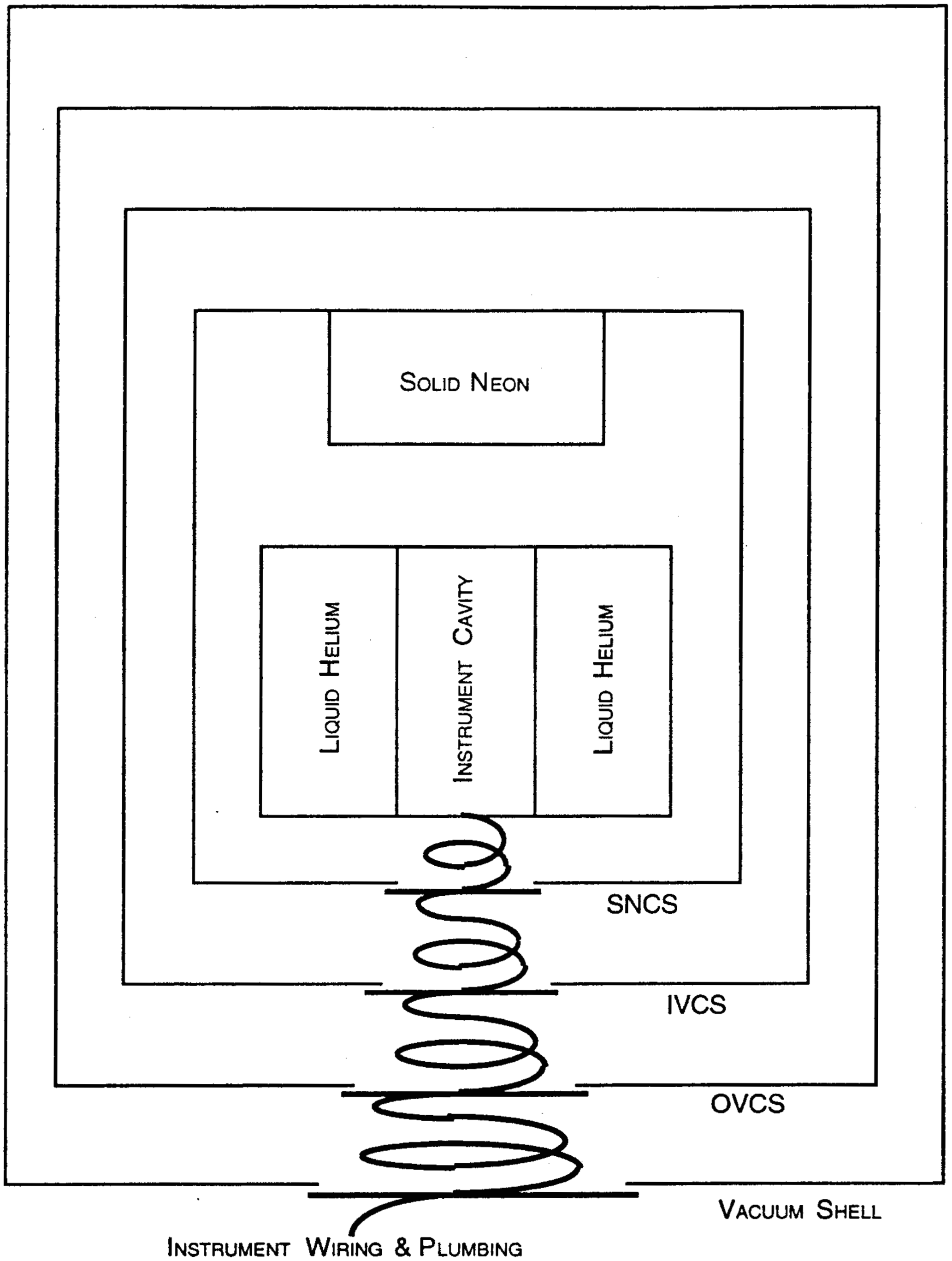

Figure 3.1 Schematic block diagram of baseline cryostat design

The instrument cavity, helium reservoir and neon reservoir volumes have been designed to maximize science return in terms of both experiment volume and cryogenic lifetime within the constraints of the Hitchhiker carrier. The cryostat lifetime is anticipated to be the same or better than the Low Temperature Platform dewar in which the LPE and CHeX instruments flew.

The annular helium reservoir has an effective volume of ~ 15 liters, with approximately 2 liters of ullage volume. The instrument cavity has an interior diameter of 16.51 cm (6.5 inches) and a depth of 30.48 cm (12 inches). The instrument cavity has a vacuum independant of the cryostat vacuum when sealed with the instrument cold flange. Heat transfer from the instrument to the helium is accomplished via conduction through reservoir walls.

On the launch pad, the vented helium vapor cools the Solid Neon (SNe) reservoir, the inner vapor cooled shield (IVCS) and the outer vapor cooled shield (OVCS). Once on orbit, vapor from both the sublimating Neon and the boiling Helium cool the inner & outer vapor cooled shields (IVCS & OVCS). The cryostat includes instrumentation for monitoring reservoir, vapor cooled shields and outer shell temperatures; helium volume/mass; and cryostat vacuum.

The nominal helium temperature at equilibrium on orbit will be 1.8 ± 0.1 K with $\pm$ 50 mK stability[c]. The system has been designed to accomodate a typical 10 mW instrument dissipation.

4. Instrument Subsystem

There are only a few fundamental limits on the instruments investigators may fly in the FACET facility. In addition to the requirements placed on all hitchhiker shuttle payloads, the FACET specific limitations include: instrument mass (15 kg), instrument cold volume (6.5 liters) and fundamental (structural) resonance frequency (> 35 Hz). It should be noted that shuttle safety requirements (in particular the requirements on pressurized volumes) can become strong drivers of instrument design.

For those investigators whose instrument closely matches the functionality of previous low temperature investigations, a multipurpose probe design will be available to lessen the development burden. Investigators are free, within programmatic resource constraints, to develop their own instruments. Only interface constraints such as cold flange area and clearance, heat leak, and instrumentation (electronics) capabilities limit the instruments that can be supported by the FACET facility.

The multipurpose probe design has three stages of thermal isolation with germanium resistance thermometer (GRT) servo control in addition to a sample stage with high resolution thermometer (HRT) servo control. The multipurpose probe design also has one stage of thermal isolation with GRT servo control shared by all SQUID sensors. The multipurpose probe design supports 4 SQUID sensors which can be used for any combination of superconducting readout devices (HRTs, pressure sensors, etc.). The baseline HRT for the multipurpose probe is a self charging (permanent magnet) "mini" HRT of the type under development at JPL, UCSB and elsewhere. The cylindrical volume within the radiation shield around the sample stage attachment point in multipurpose probe design is approximately 11 cm in diameter by 11 cm tall. The baseline flight design has a charcoal getter pump to remove the exchange gas added before launch to keep the instrument cool during the heating induced by launch loads. The multipurpose probe design also includes a circulator line for precooling the instrument, as well as lines for sample fill and pneumatic (prelaunch) actuation of a normally closed cryovalve. An assembly drawing of a multipurpose probe design is shown in Figure 4.1.

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[c] Higher or lower equilibrium temperatures may be achieved by modification to the porous plug liquid/vapor phase separator or the addition of secondary refrigeration (i.e. ^{3}He sorption) within the instrument cavity.

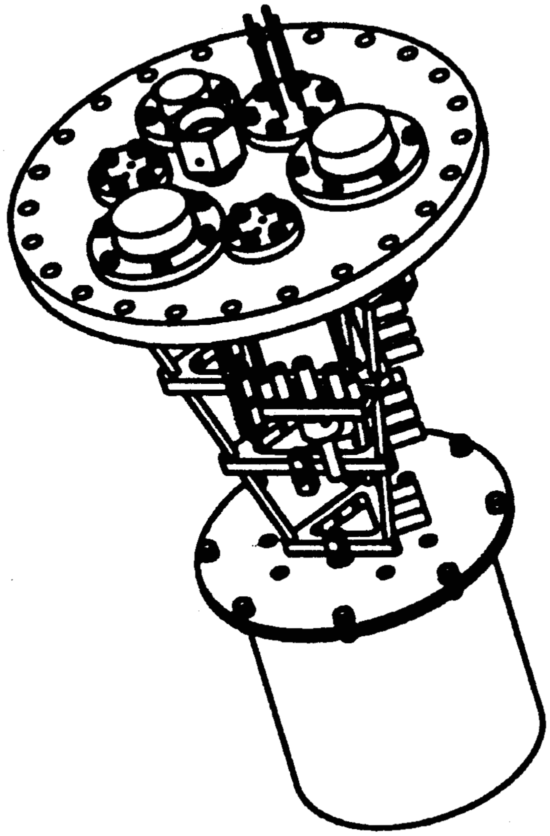

Figure 4.1 Assembly drawing of a multipurpose probe design

Thermal anchoring of of all electrical leads, plumbing, etc. from the instrument is made at the closure plates on the solid neon cooled shield, as well as both the inner and outer vapor cooled shields.

5. Electronics Subsystem

Since the FACET facility is intended for reflights supporting various investigators, the ability to customize the instrumentation to meet the needs of the present flight definition PIs and future PIs has been a design consideration from the beginning.

The electronics proposed for FACET is based on the Station Processor and Electronics Control (SPEC) development work with a heritage that includes CHeX and LPE. The functions performed by the LTP Experiment Controller Assembly (ECA), Facility Electronics Assembly (FEA), and Power Conditioner Assembly (PCA) for CHeX would be combined into a single ATR style box (a longer version of the same standard used for CHeX.) The underlying architecture is based on the CHeX ECA. The instrument and cryostat functions performed by the LTP Main Electronics Assembly (MEA), Telemetry and Command Assembly (TCA), and Cryo Engineering Assembly (CEA) for CHeX/LPE would be performed by SPEC type cards included in the ATR chassis. The SPEC cards greatly reduce the number of boards required while retaining the redundancy provided by separating stages and stage redundant sensors to different boards.

The software changes required to the CHeX application code are minimal and are primarily in the addressing and Digital Signal Processor (DSP) specific code. The scientific routines to handle pulsing, sequencing, telemetry, and commands do not require changes. At the same time, enhancements may be added to both the flight and ground processing software on a modular basis as desired. In particular, the completed system could serve as a LabView testbed without modification for either flight software, ground software, or both.

Under the SPEC program, a general purpose slot interface for real time use was developed based on a programmable DSP. This interface provides a standard interface for all boards which is fully programmable and requires no onboard nonvolatile memory. Consequently, the sensor unique development is limited to the portion of each board between the opto-isolated DSP and the sensor. Digital functions are carried out directly by the DSP using opto-isolators and possibly additional digital circuitry (e.g. for SQUID digital reset.)

The ATR chassis is suitable for use in the Shuttle payload bay or a free-flyer and will fit in a standard GAS Can cylinder.

Figure 5.1, below, is a hierarchical architecture block diagram, depicting the 5 major functions of the electronics subsystem; power, telemetry & command, cryostat I/O, Instrument I/O, and environmental monitoring. Items in *italics* are possible development options. There will be a limit on the total number of instrument data channels, yet to be determined, that will be set by the volume constraints of the carrier. Early feasibility studies indicate that it should be possible to support a number of data channels comparable to what was required to conduct the LPE and CHeX experiments. Power functions principally involve filtering and distribution functions (e.g. the activation of cryogen vent valves once on orbit). Environmental monitoring is envisioned to include both charged particle and "g-jitter" acceleration measurement comparable to what was required to conduct the LPE and CHeX experiments.

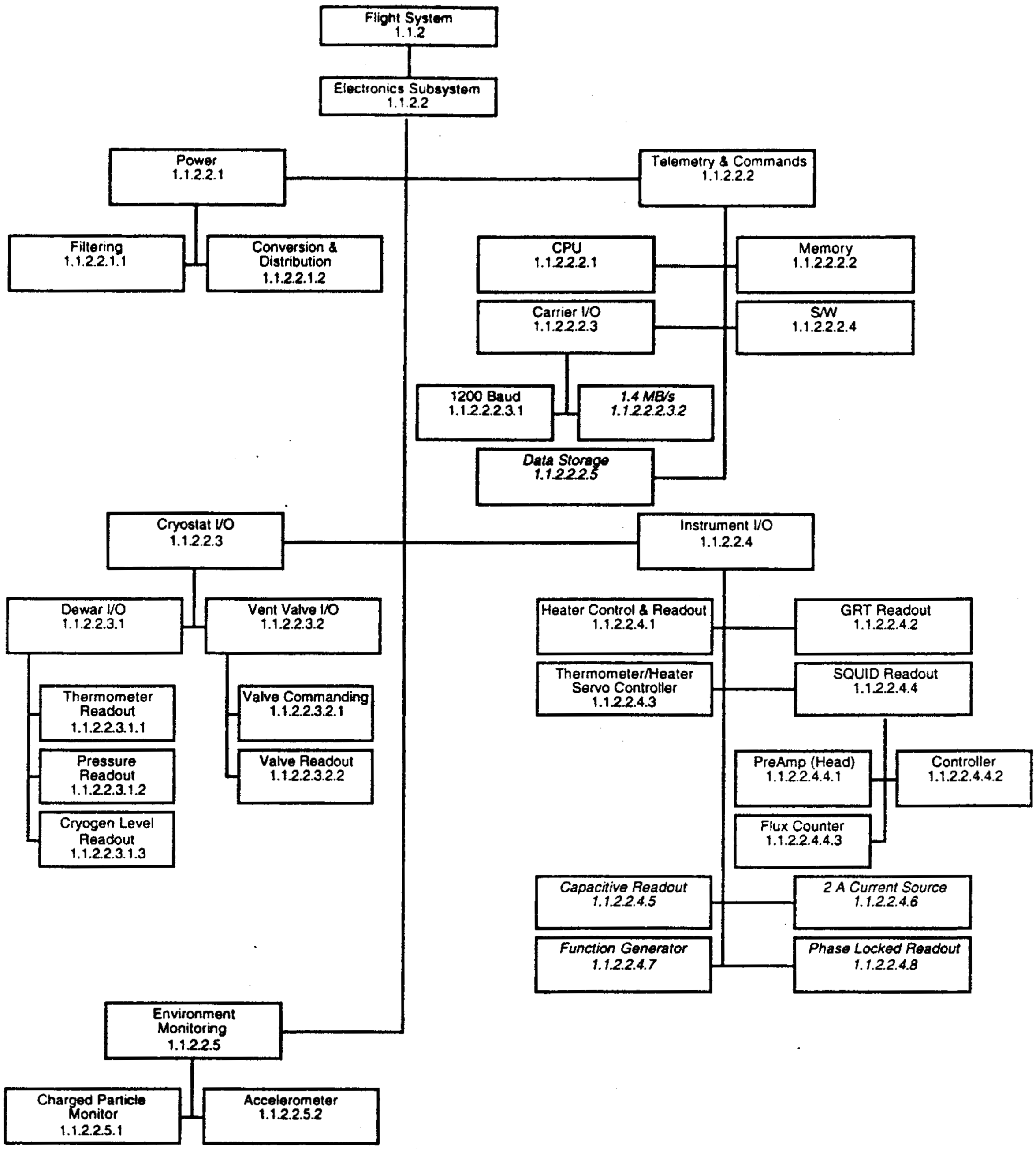

Figure 5.1 Electronics Subsystem Architecture Block Diagram

Acknowledgement

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